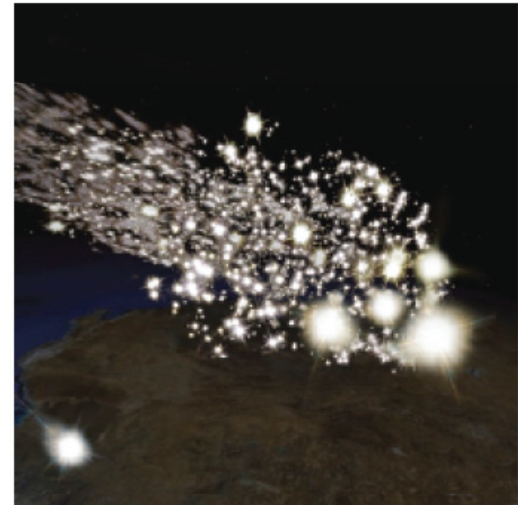
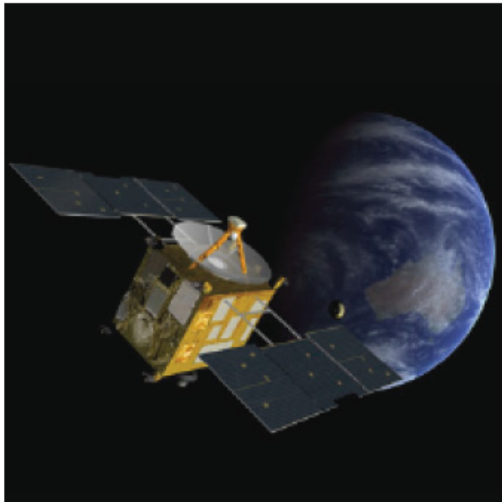


Japanese Hayabusa Asteroid Sample Return

JPL Stories

Presented by Dr. Tommy Thompson,
Muses-C Project Manager

March 2, 2011



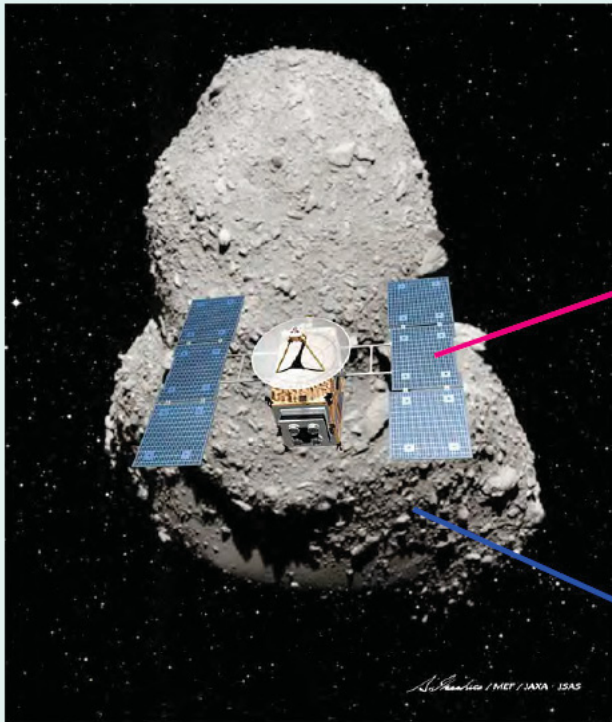
Jet Propulsion Laboratory, California Institute of Technology.

Copyright 2011. California Institute of Technology. Government sponsorship acknowledged.

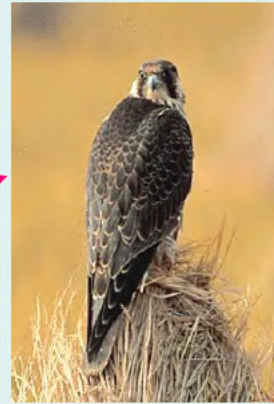
Topics

- Mission Overview
- Rendezvous—September to November 2005
- Reentry—January 2009 to June 13, 2010
- Hayabusa-2

Hayabusa and Itokawa



Hayabusa at asteroid Itokawa



Falcon

はやぶさ

Hayabusa

Itokawa



イトカワ

**Named after the late Prof. Hideo.
Itokawa, the Father of Modern
Japanese Rocketry**

Asteroid (25143) Itokawa

S-type asteroid / Near-Earth Object

~ 550 × 298 × 258 m (the smallest visited by a spacecraft)

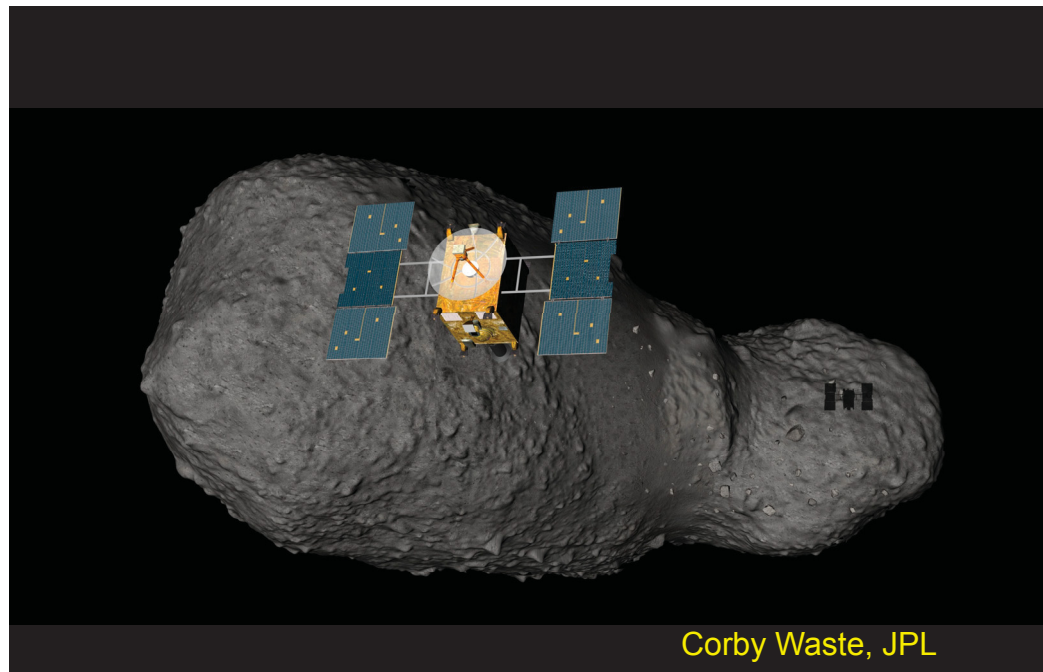
Retrograde rotation period = 12.1 hours about shortest axis.

Pole nearly perpendicular to ecliptic plane.

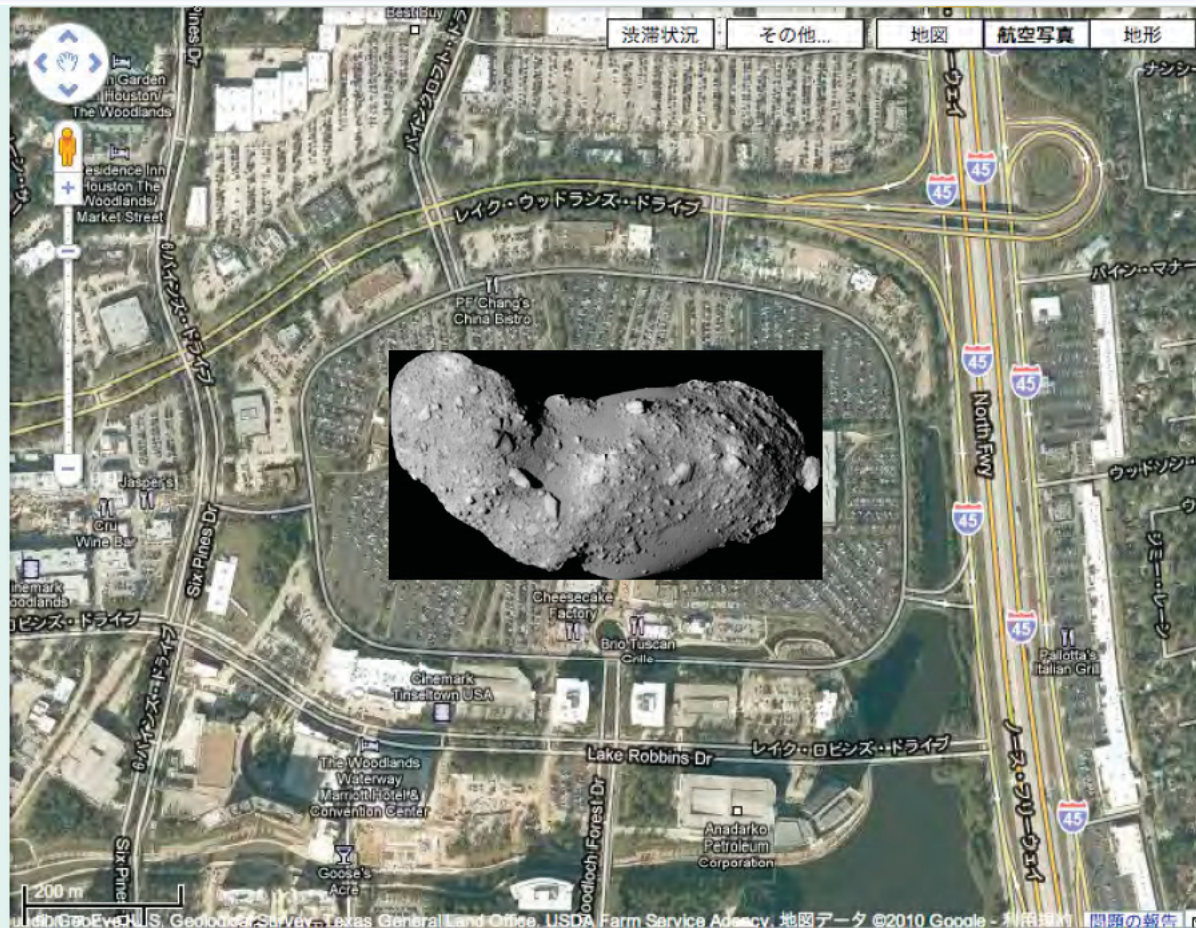
Best meteorite analog: L or LL ordinary chondrite

Albedo: 0.35 – 0.55

Bulk density ~ 2.3 +/- 0.3 g/cm³

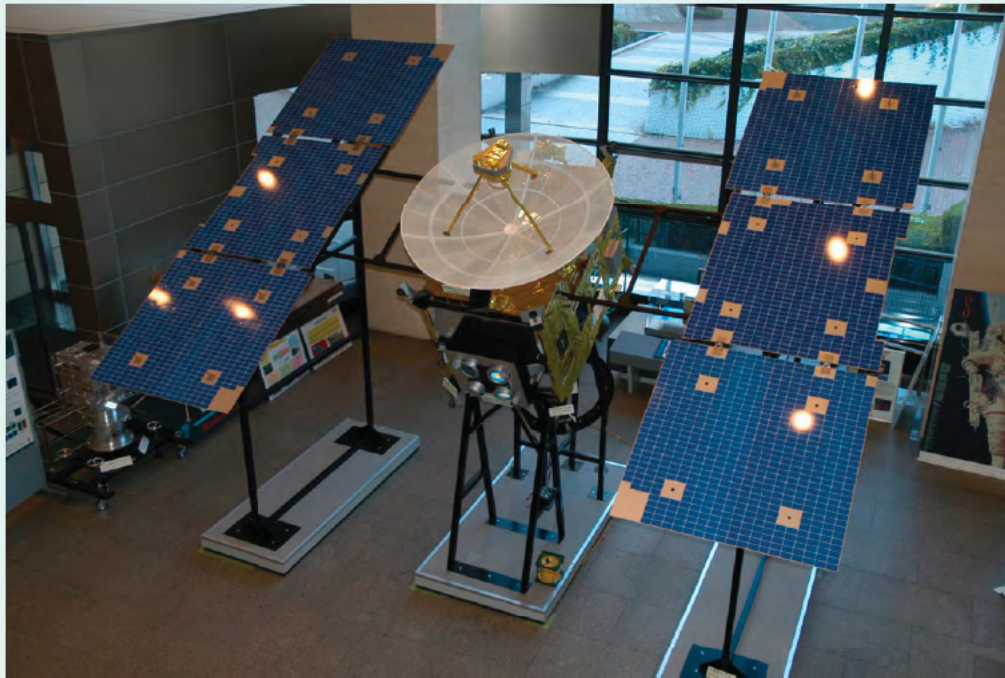


Itokawa : Very small asteroid



Courtesy of Dr. Makoto Yoshikawa, JSPEC

Asteroid Explorer 'Hayabusa'



Real-sized model of Hayabusa displayed at Sagamihara campus of JAXA

Size: 1.0m x 1.6m x 1.1m
Mass: 380kg (Dry)
Chemical Fuel: 70kg
Xe Propellant: 60kg
Wet Mass: 510kg
Power: 2.6kW@Earth
RF: X-band

Courtesy of Dr. Makoto Yoshikawa, JSPEC

New Technology in Hayabusa

Five Key Technology to be demonstrated :

1. Interplanetary Cruise via **Ion Engines** as Primary Propulsion
Microwave driven & CC Grid Ion Engine
2. **Autonomous Navigation and Guidance** using Optical Measurement
3. **Sample Collection** from Asteroid Surface under Micro Gravity
4. **Direct Reentry** for Sample Recovery from Interplanetary Orbit
5. Combination of **Low Thrust and Gravity Assist**

Other New Technology introduced :

Bi-Propellant Small Thrust Reaction Control System (20N),
X-band Up/Down Communication, Complete CCSDS Packet Telemetry,
Duty Guaranteed Heater Control Electronics,
Wheel Unloading via Ion Engines, PN-Code Ranging,
Lithium Ion Re-chargeable Battery, Multi-Junction Solar Cell, etc.

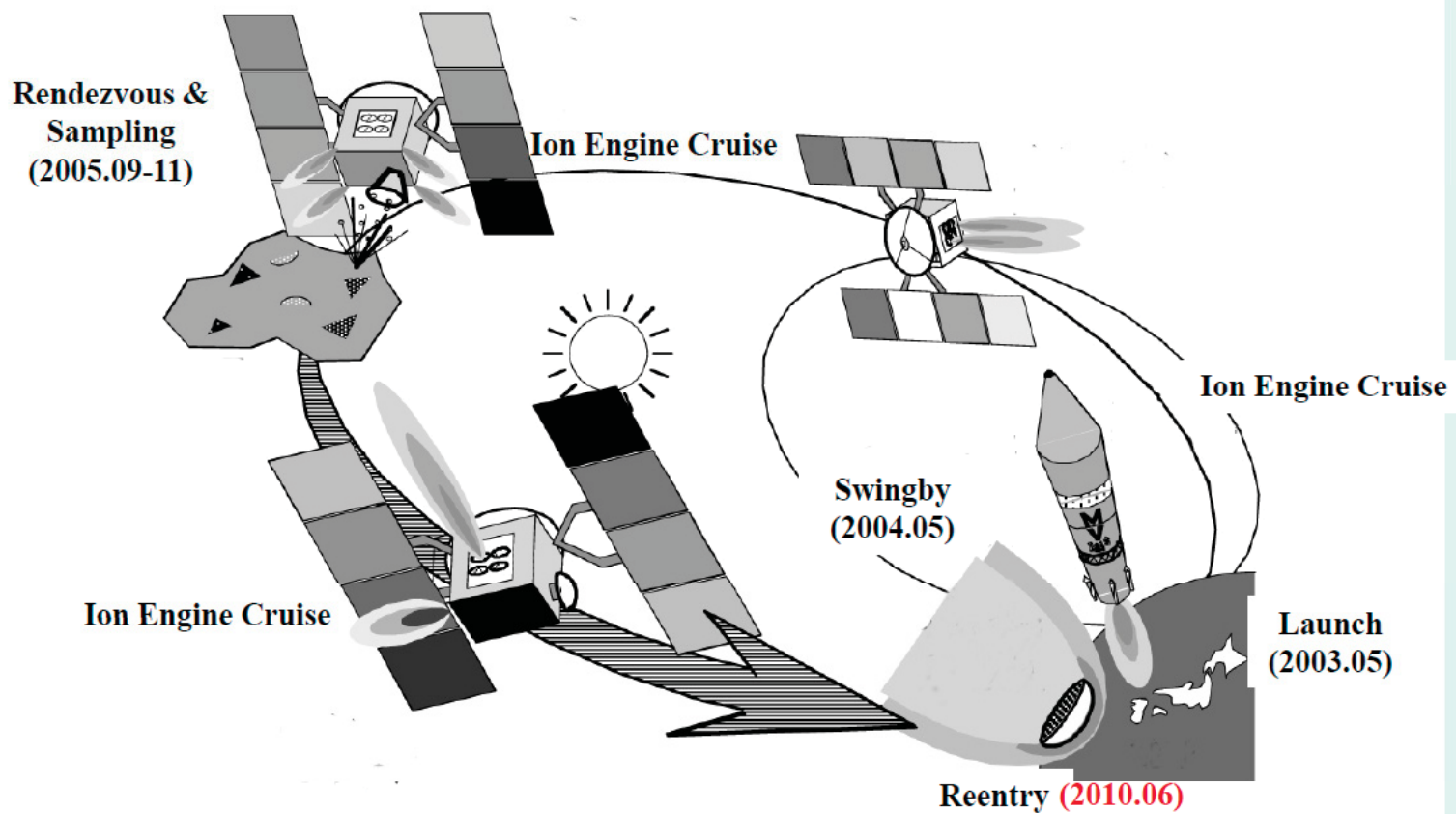
NASA-JPL Support of Hayabusa (Muses-C Project at JPL)

- Pre-launch testing of the heat shield material (NASA Ames)
- Investigators on the Rendezvous remote sensing instruments
- Sample scientists
- Parallel navigation
- DSN tracking (Command/Telemetry, Delta DORs, Doppler)
- NASA Ames DC-8 observations of Reentry fireball

Muses-C = Mu Space Engineering Spacecraft-C

Technology Demonstrator launched on Mu rocket

Hayabusa Mission History

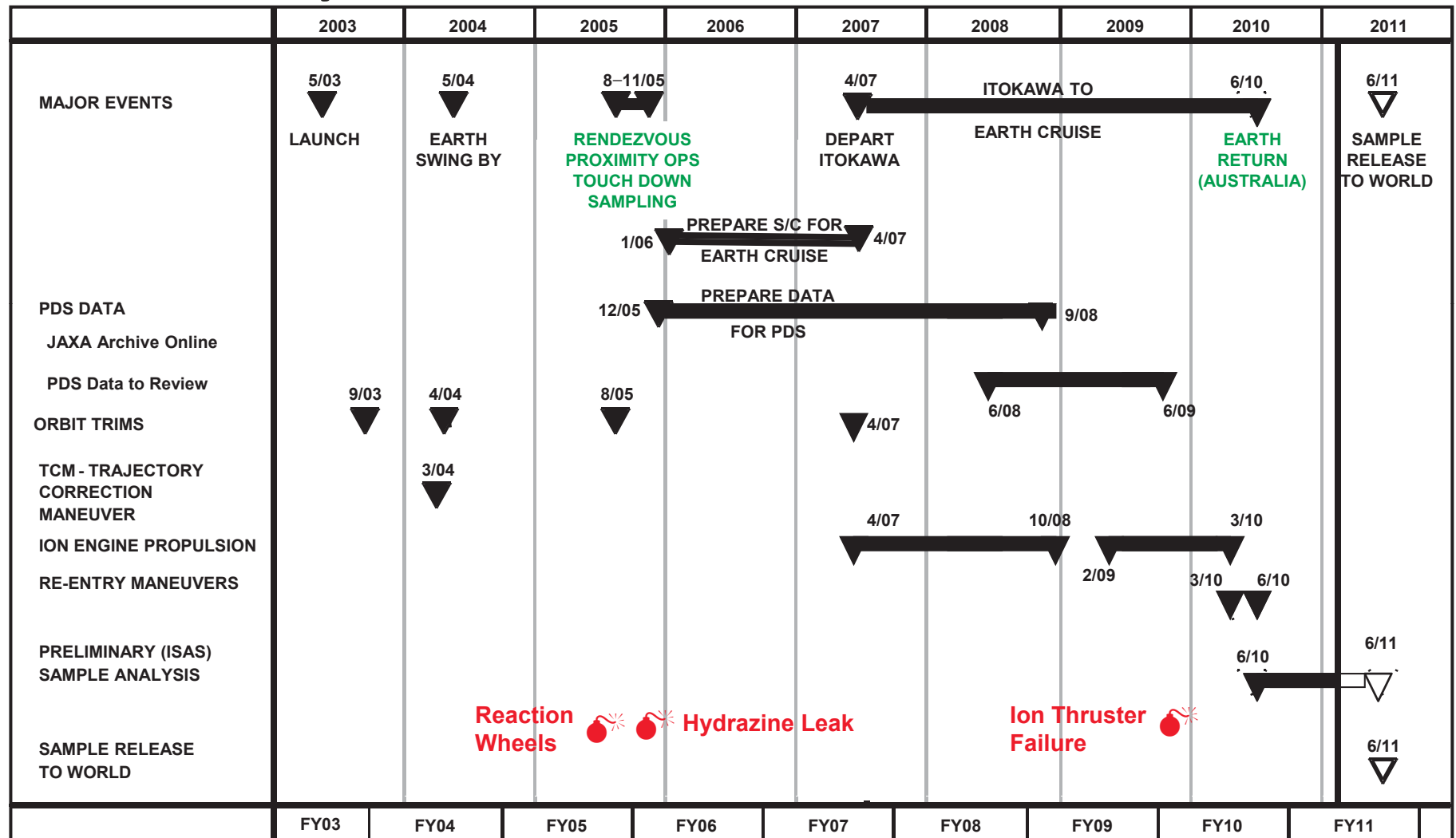


Courtesy of Dr. Makoto Yoshikawa, JSPEC

Mission Overview

- May 9, 2003 – Launch – JAXA M-V Rocket from Kagashima Space Center
- May 19, 2004 – Successful Earth Swing-By
- **July 31, 2005 – Reaction Wheel Damaged**
- September 12, 2005 – Start of Rendezvous – 20km from Itokawa
- November 20, 2005 – First Landing on Itokawa – Landing by Target Marker
- November 26, 2005 – Second Touchdown on Itokawa – **Hydrazine Leak**
- **December 8, 2005 – Loss of Attitude Control and Communications**
- January 23, 2006 – Resume Beacon Signal
- July 2006 – Establish of Auto-tracking to Sun by Solar Pressure
- September 2006 – Recharging of Lithium Batteries
- January 17, 2007 - Transfer of Sample Canister to Reentry Capsule
- April-October 2007 – First Orbit Transfer to Earth
- February 2, 2009 – Start of Second Orbit Transfer to Earth
- **November 2009 – Ion Thruster Failure and Recovery**
- March 2010– Start Reentry Phase
- **June 13, 2010 – Successful Reentry in Australia**
- November 2010 – JAXA Press Release – Samples are asteroidal !
- June 2011 or later – Release of samples via International AO

Hayabusa Mission Schedule

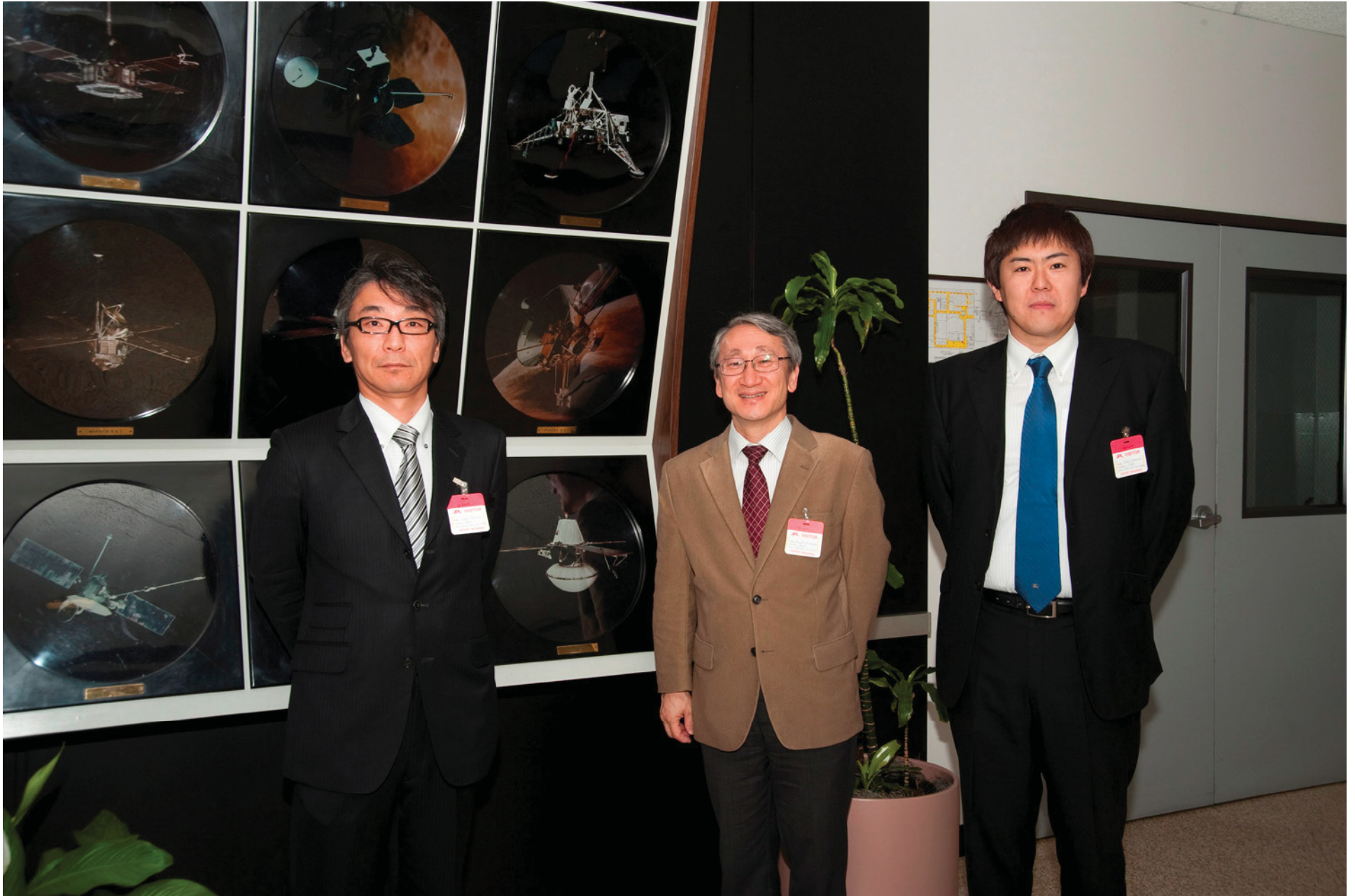


Visit to the spacecraft
before launch



Key Players: Japanese Project Team

- Professor Jun'ichiro (Jun) Kawaguchi, Project Manager
- Dr. Hitoshi Kuninaka, Operations Manager
- Dr. Makoto Yoshikawa, Chief Navigator and Project Scientist
- Dr. Matsuoka Masatoshi, Navigation
- Dr. Takahiro Yamada, Tracking Manager
- Dr. Tetsuya Yamada and Dr. Hajime Yano, Recovery Operations



Left to right - Hitoshi Kuninaka, Junichiro Kawaguchi, Hideto Yamazaki

Key Players: Science Team

- Don Yeomans – US Project Scientist
- Andy Cheng and Olivier Barnouin-Jha (APL, LIDAR)
- Peter Smith (LPL, University of Arizona) and Dave Tholen (University of Hawai'i, AMICA)
- Faith Vilas (LPL, University of Arizona) and Beth Clark (Ithaca College, Cornell University, NIRS)
- Paul Abel (JSC, PDS and Reentry Field Team)
- Carol Neese and Don Davis (PSI, Tucson, PDS Small Bodies Sub-Node)
- Bob Gaskell* (JPL and PSI, Shape Models)
- Dan Scheeres* (University Of Colorado, Rendezvous Liaison)
- Mike Zolensky, Scott Sandford, Trevor Ireland (JSC, Ames, Australian National University; Sample Scientists)

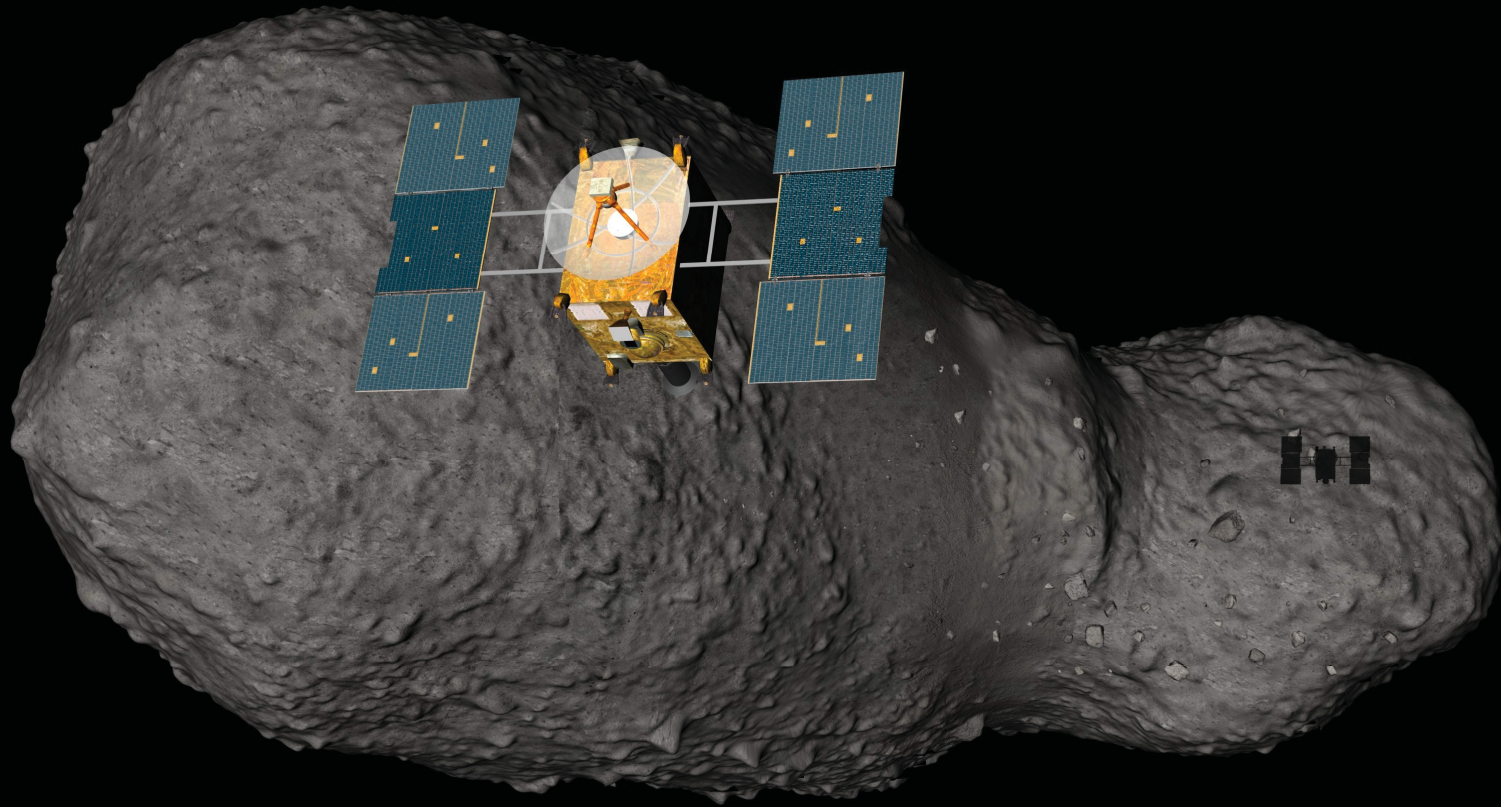
*Personnel located in Japan

Joint Science Team



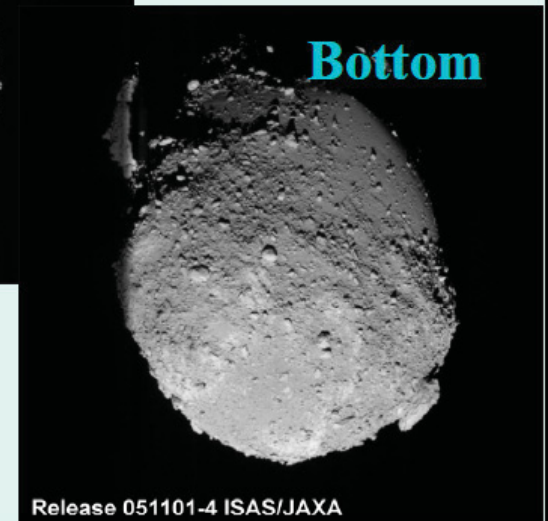
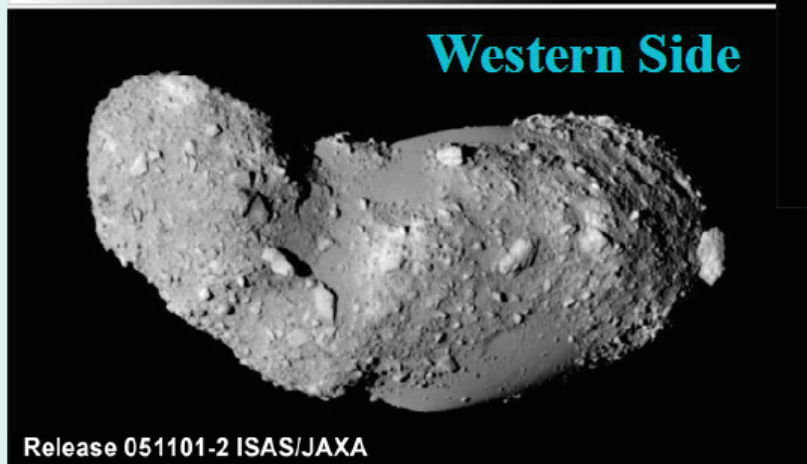
Rendezvous–September to November 2005

Itokawa Rendezvous
Sept.-Nov. 2005



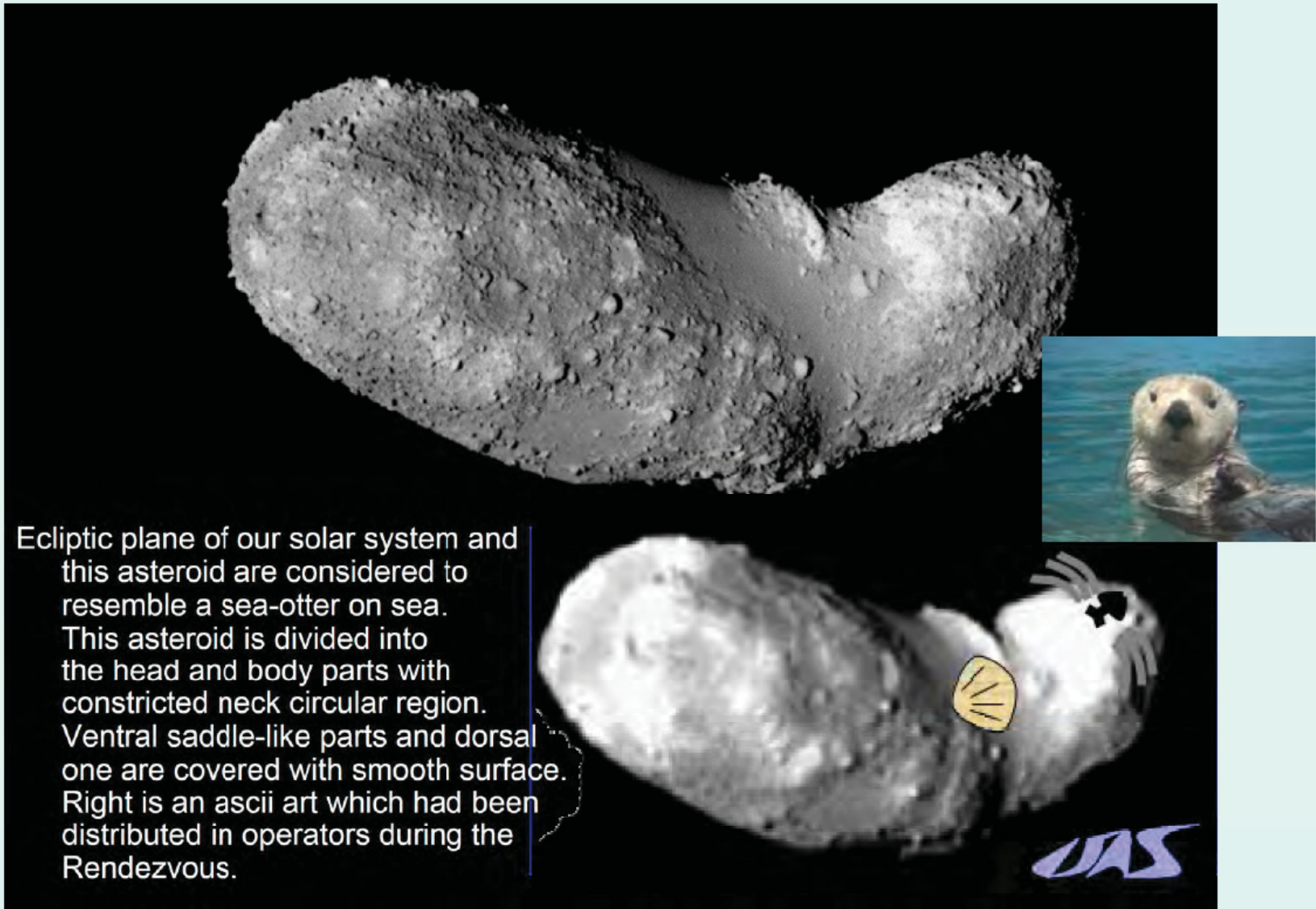
Corby Waste, JPL

Images of Itokawa : whole

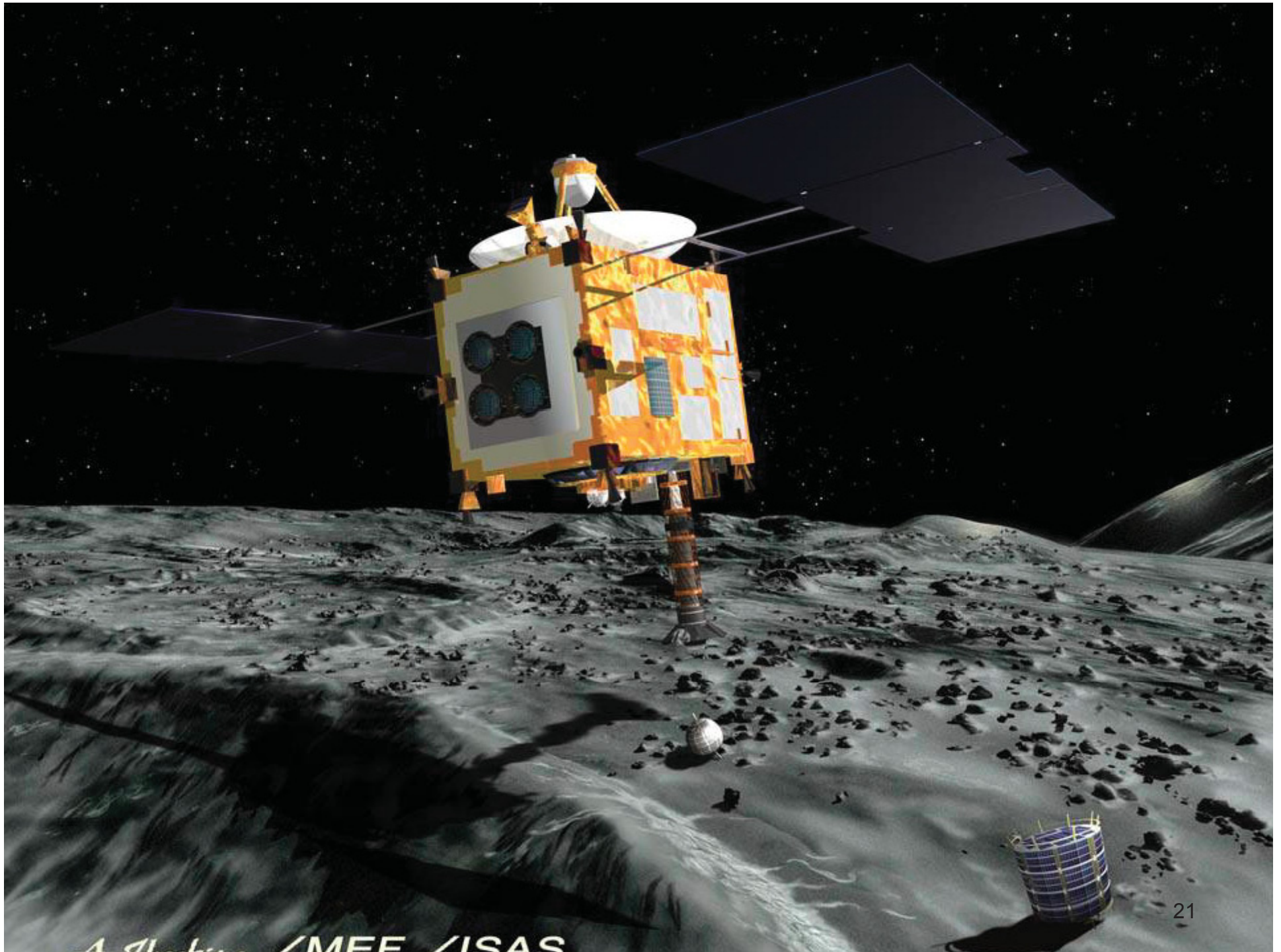


Courtesy of Dr. Makoto Yoshikawa, JSPEC

Global Shape of Itokawa: Sea Otter in Space?



Courtesy of Dr. Makoto Yoshikawa, JSPEC



Hayabusa Touchdown November 2005

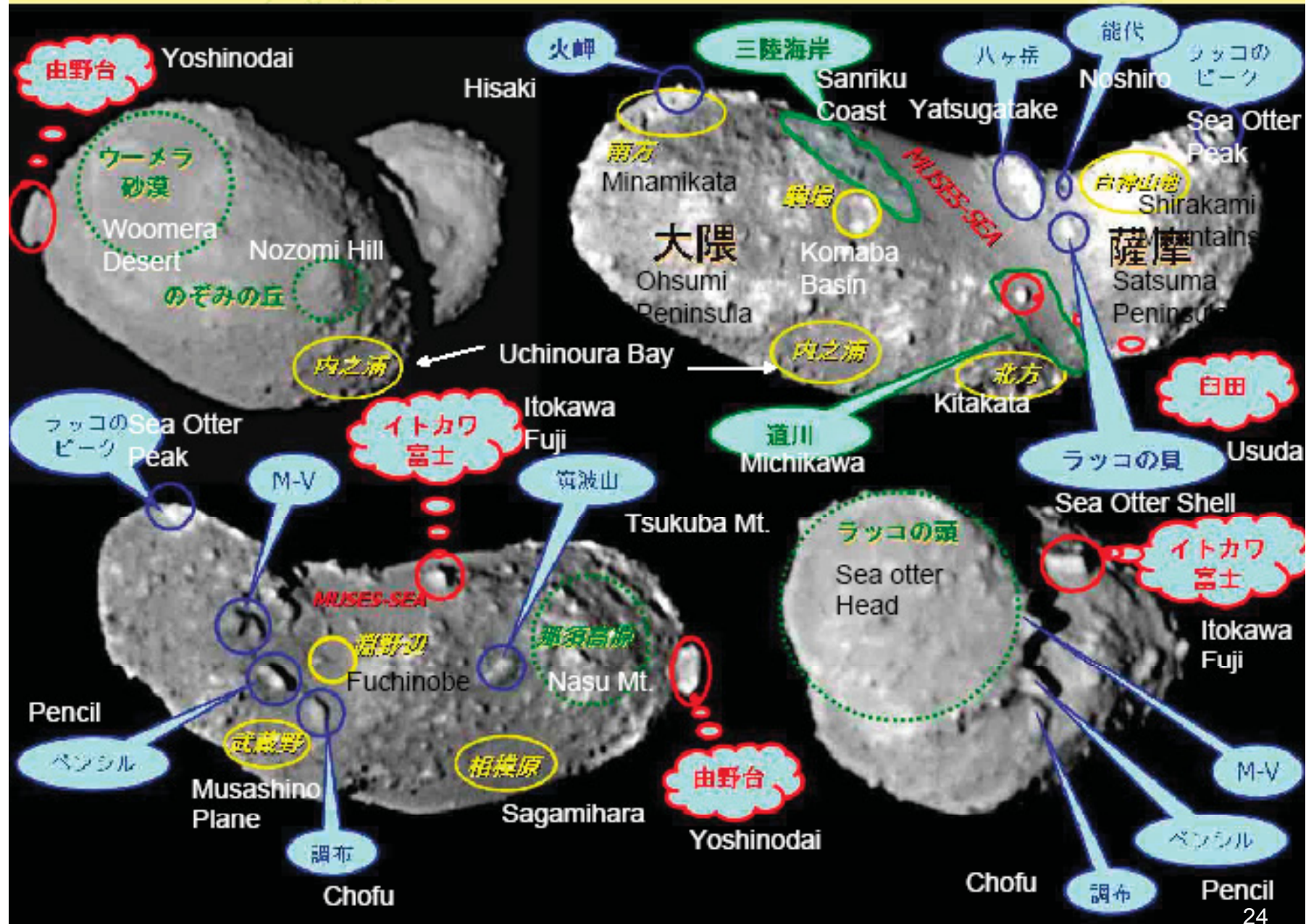


Corby Waste, JPL

Preliminary Science Results

- Size: $550 \times 298 \times 258$ m
- Rotation period: 12.1 hours
- Spectral similarities to LL Chondrites or Primitive Achondrites
- There are slight color differences across surface
- Very few obvious impact craters – relatively young surface
- Very rough angular blocks on most of surface – rubble pile?
- Some smooth areas seem to follow gravity wells – redder than surroundings
- No extensive lineations (as there were on Eros) → may imply no pervasive fabric
- Largest boulder: ~30 m long and ~ 20 m high
- Some high pinnacles and many boulders that seem to be just barely attached to surface. Could be “bedrock” showing through those areas without regolith.
- Surface suggestive of disruption followed by re-agglomeration

イトカワ地名候補



Key Players: Through Rendezvous

- Ross Jones and Joel Smith (JPL, Project Managers)
- Neil Mottinger, Mark Ryne, Jordan Ellis, Shyam Bhaskaran,* Rob Haw,* Al Cangahuala (JPL Navigators)
- Dan Scheeres* (University Of Colorado, Liaison)
- Bob Gaskell* (JPL, Liaison)
- Belinda Arroyo and Chris Page (JPL, DSN Schedulers)
- Albert Chang and Steve Waldherr (JPL, DSN Operations)


*Personnel located in Japan















Reentry

January 2009—June 13, 2010

Hayabusa Schedule 2009–2010

ITEM	2009												2010					
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J
S/C S/W MODS	▼																	
ION THRUSTING		←																
DELTA-DORS									▼			▼			▼		▼	
THRUSTER FAILURE																		
DATA FLOW TEST													3/22–26	▼				
TCM 0 (EARTH-RIM)															▼	4/4–6		
TCM 1 (EARTH-RIM)															5/1–4	▼		
TCM 2 (EARTH-RIM)															5/22–28		▼	
TCM 3 (WPA CENTER)																6/2–5		▼
TCM 4 (WPA LANDING)																6/10		▼
REENTRY (6/13)																	6/13 ✱ (13:53 UTC)	
VCO LAUNCH WINDOW															5/17 – 6/02	▼	▲	
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J

Hayabusa Schedule March-June 2010

	MARCH					APRIL					MAY				JUNE		
ITEM	2/28 – 3/04	3/07 – 3/13	3/14 – 3/20	3/21 – 3/27	3/28 – 4/03	4/04 – 4/10	4/11 – 4/17	4/18 – 4/24	4/25 – 5/01	5/02 – 5/08	5/09 – 5/15	5/16 – 5/22	5/23 – 5/29	5/30 – 6/05	6/06 – 6/12	6/13 – 6/19	
ION THRUSTING																	
DELTA-DOR'S																	
TCM 0 (EARTH-TIM)						4-6 APRIL (EARTH-RIM)											
TCM 1 (EARTH-RIM)											1-4 MAY (EARTH-RIM)						
TCM 2 (EARTH-RIM)																	
TCM 3 (WPA)																	
TCM 4 (WPA)																	
REENTRY																	
VCO LAUNCH WINDOW										17 MAY						02 JUNE	
											20 MAY						
	MARCH					APRIL					MAY				JUNE		

Obstacles to Reentry—January 2010 (the Perils of Pauline)

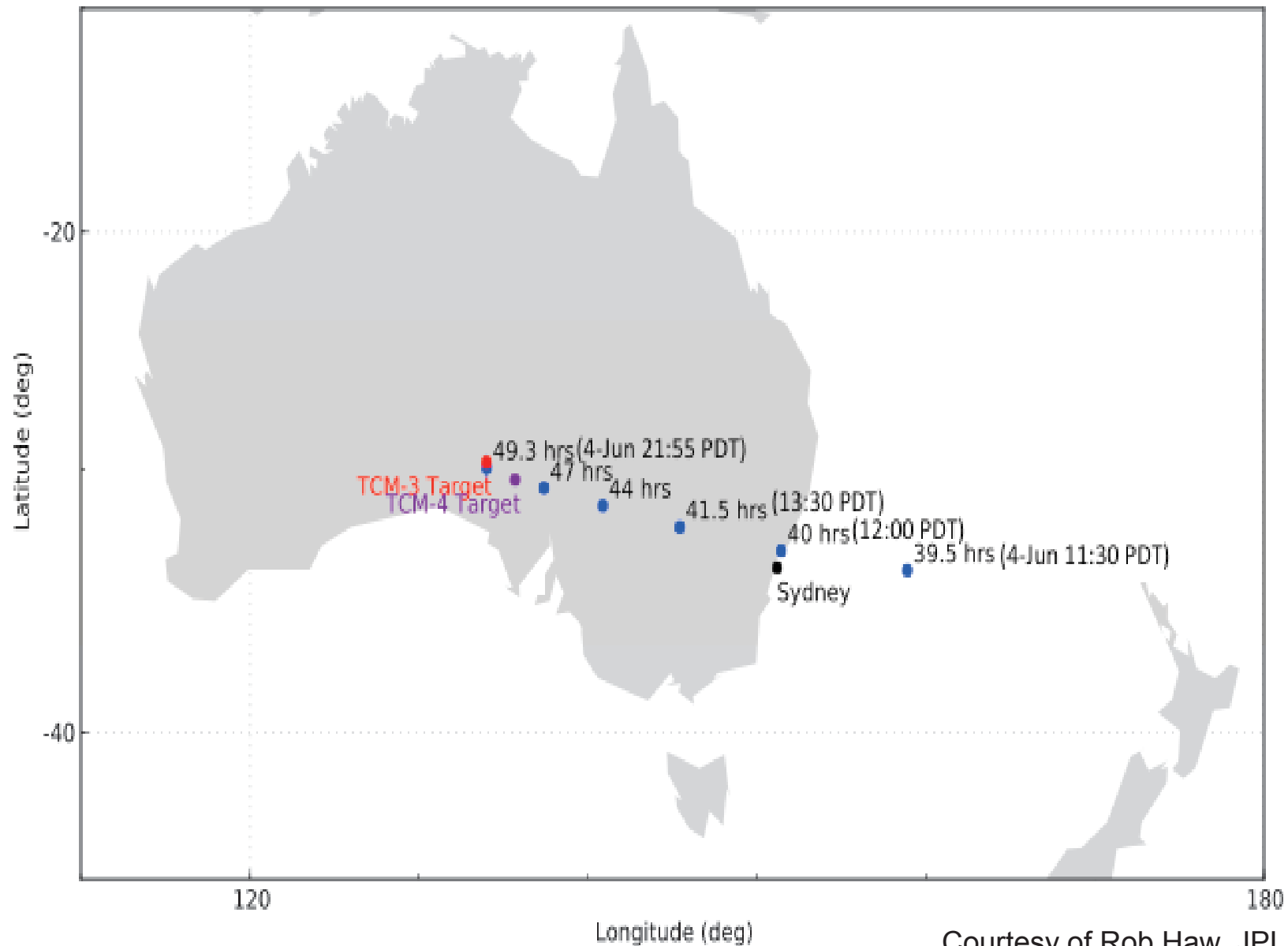
<i>Subsystem</i>	<i>Status</i>	<i>Work-around</i>
Attitude Control	2 of 3 reaction wheels failed. Chemical RCS thrusters dead. Star trackers: operational.	Stabilized with solar radiation pressure and neutralizer jets (cold gas). Single remaining wheel useful for Z-axis turns.
Power	Batteries dead. Solar panels degraded.	Solar power only. Point solar panels within $\pm 10^\circ$ of Sun to provide sufficient power.
TCMs	Chemical RCS thrusters dead.	Use ion engines. Attitude controlled by reaction wheel & gimbaling thruster. Request NASA-JPL support for maneuver determination.
Ion Propulsion	3 of 4 engines dead; remaining engine functions at low levels only; some components OK.	Combine Neutralizer A with Ion Source B to yield ~90% of nominal single-engine thrust.
Telecom	HGA functional but unusable because of pointing and thermal constraints.	Rely on low-gain antennas. NASA-DSN support for tracking & commanding.
Bus	All sub-systems reduced to single-string.	

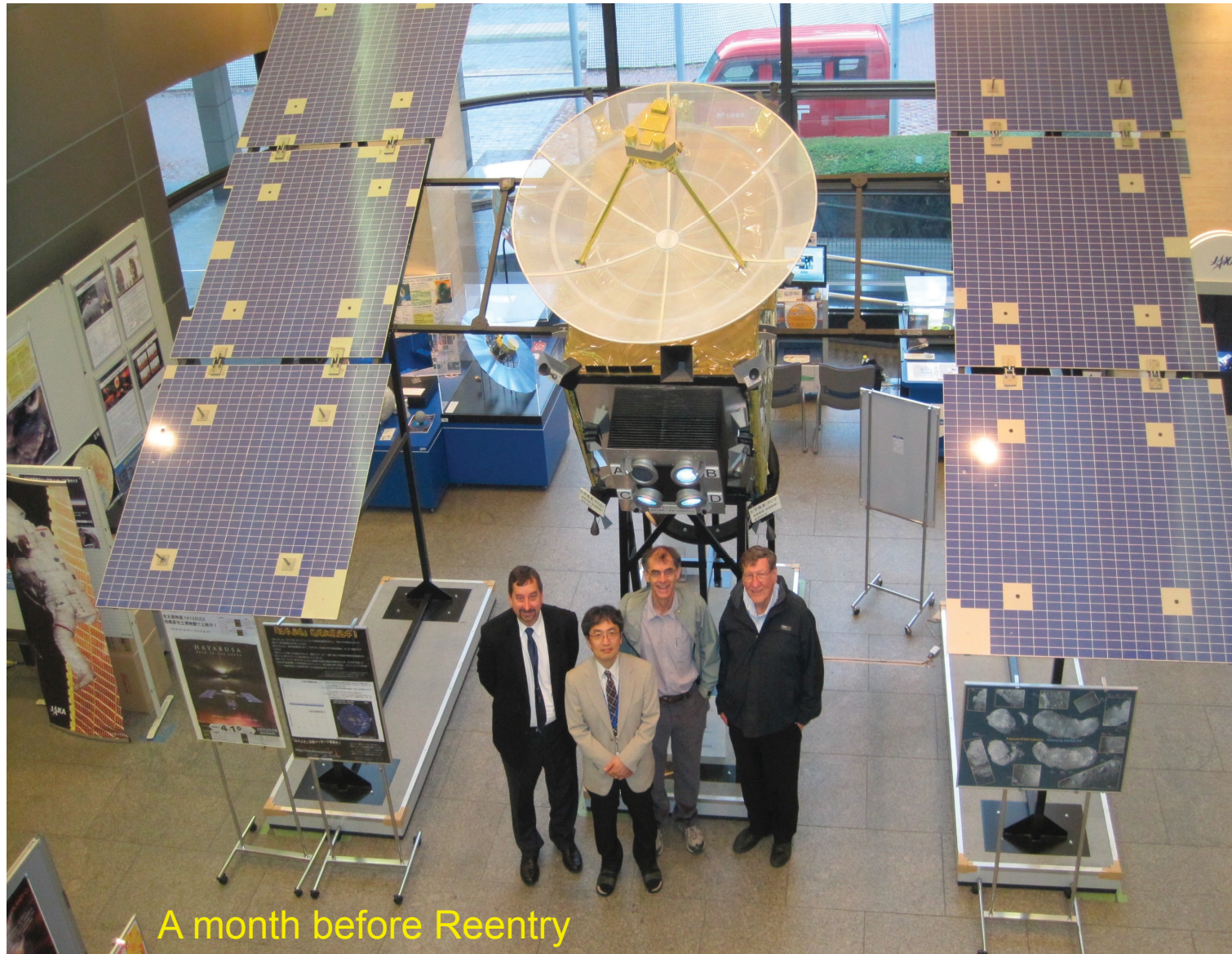
TCM History

- TCM-0 – Earth-Rim - April 4–6, 2010 - **Started a day late and ended 6 hours early, with a Delta-V of 2.0 m/s, versus a planned value of 3.0 m/s, increased total Delta-V of this and all remaining TCMs.**
- TCM-1 – Earth-Rim - May 1–4, 2010 - **Went very well. It ended 4 hours early because the ion engine performance slightly exceeded expectations. Contingency/Trim TCM wasn't needed.**
- TCM-2 – Earth-Rim - May 22–28, 2010 - **Went very well and accomplished a delta-V of 5.1 m/s. As with the second TCM, this ended a few hours early because the ion engine performance slightly exceeded expectations. The spacecraft is now headed to a point some 630 km above the earth's surface at the swing-by time.**
- TCM-3 – Woomera - June 2–5, 2010 - **Went very well and accomplished a delta-V of 2.75 m/s. The spacecraft is following its planned path to the reentry area in Australia with high fidelity.**
- TCM-4 – Woomera – June 10, 2010 - **Went very well and accomplished a delta-V of 0.14 m/s with a 2.6-hour ion engine burn - Last use of the Hayabusa's ion engines. The spacecraft continues on its planned path to the reentry area in Australia with high fidelity.**

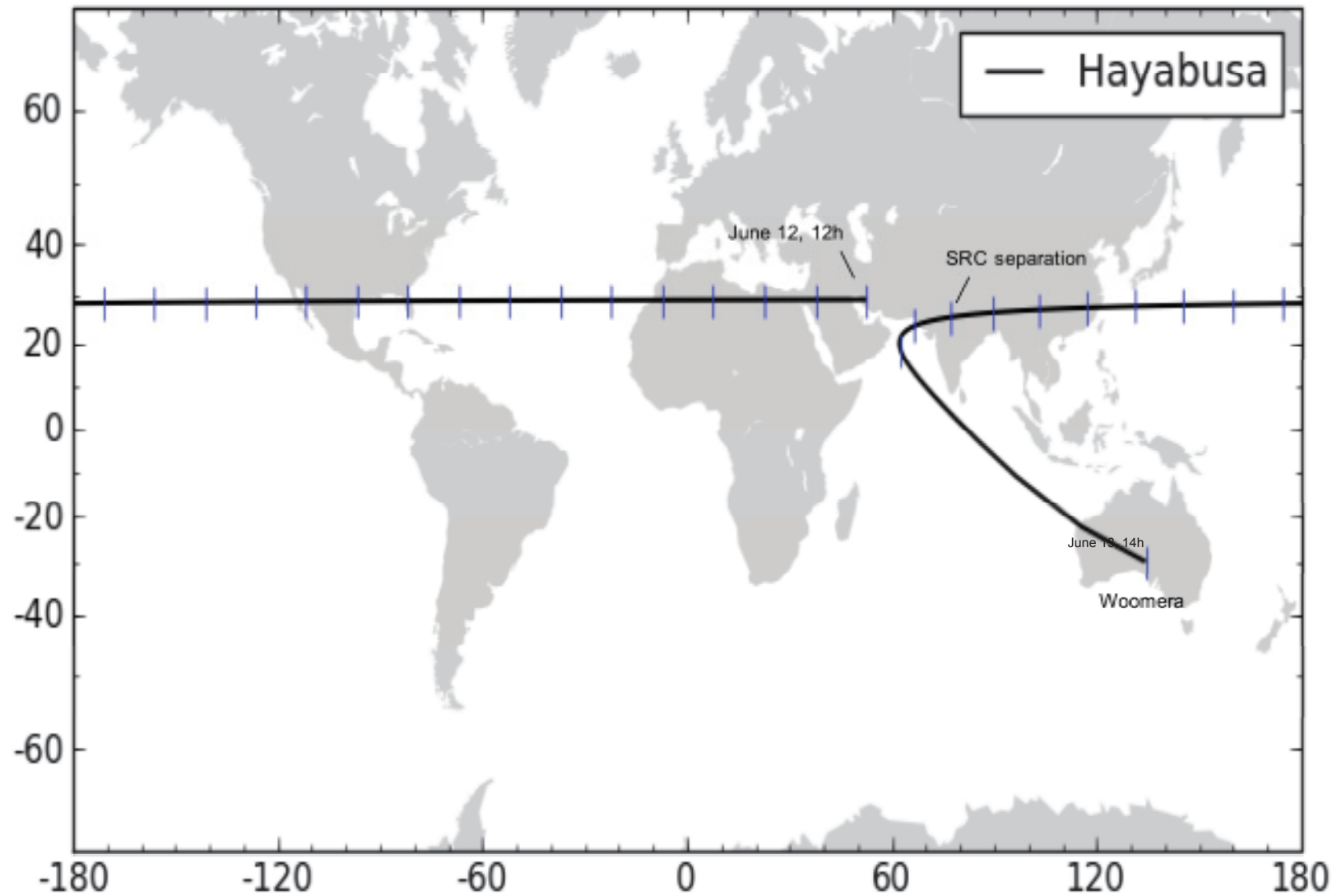
Ground Plot During TCM-3 Burn

Final TCM-3 Landing Points as a Function of Burn Time (hrs) As of 18:00 UTC (11:00 PDT)

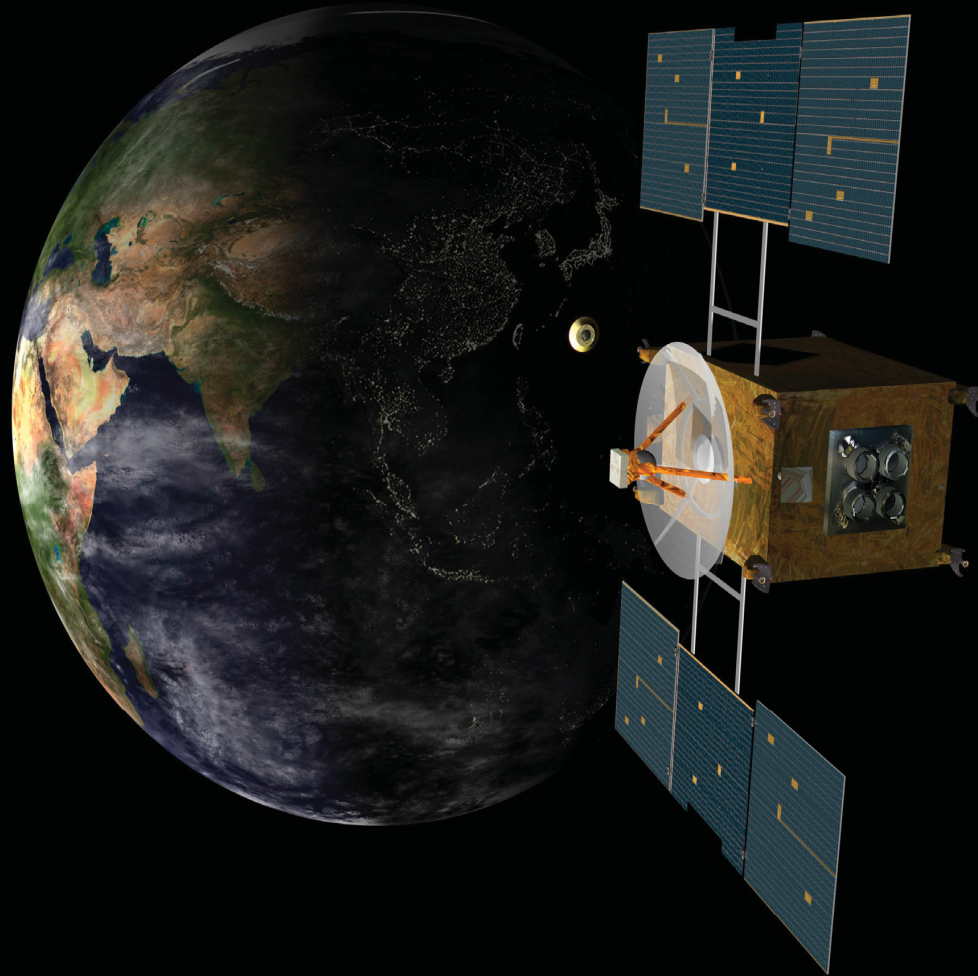




Ground Track, Last Day

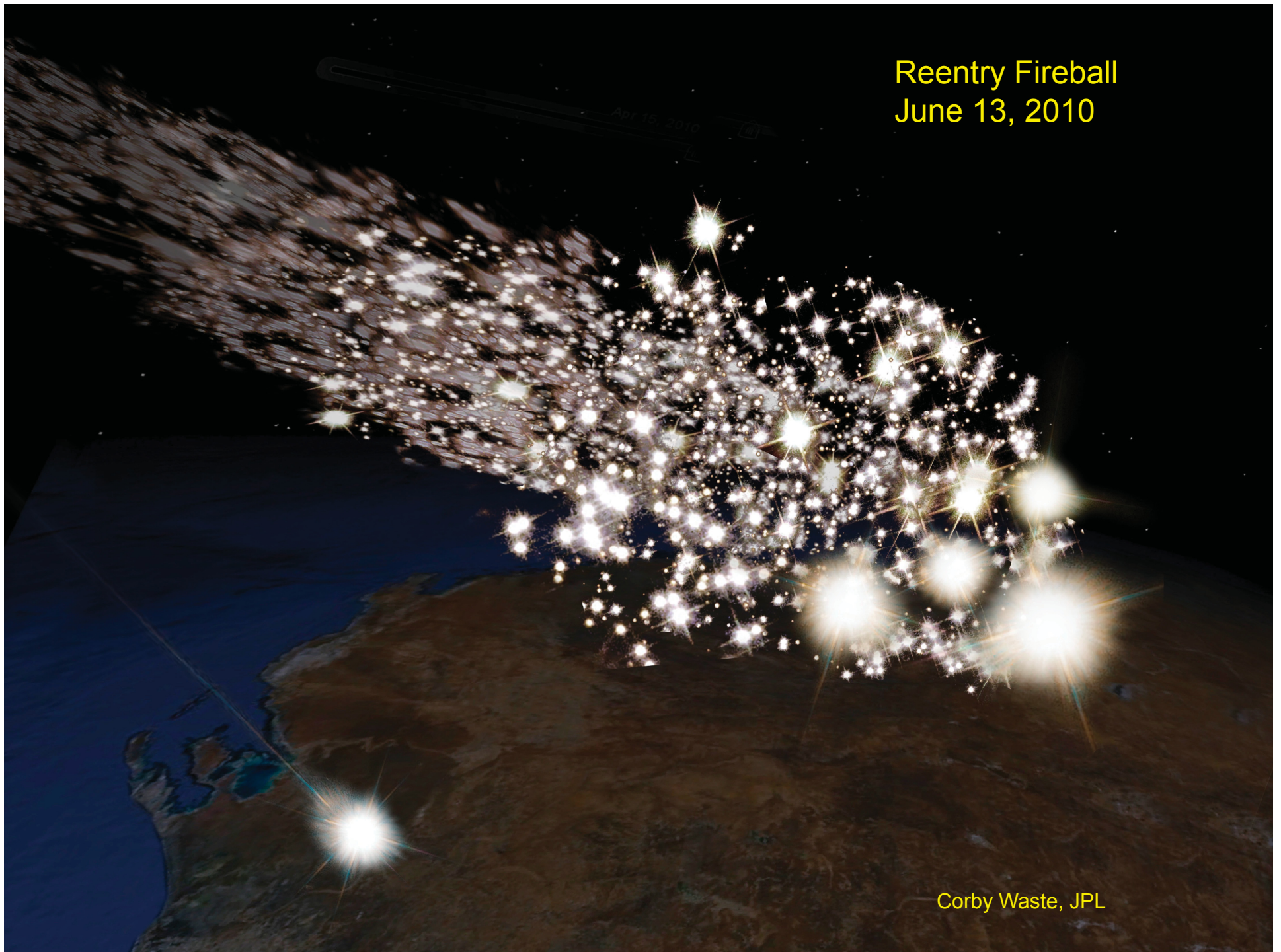


Release of Sample Canister Over India



Corby Waste, JPL

Reentry Fireball
June 13, 2010



Corby Waste, JPL

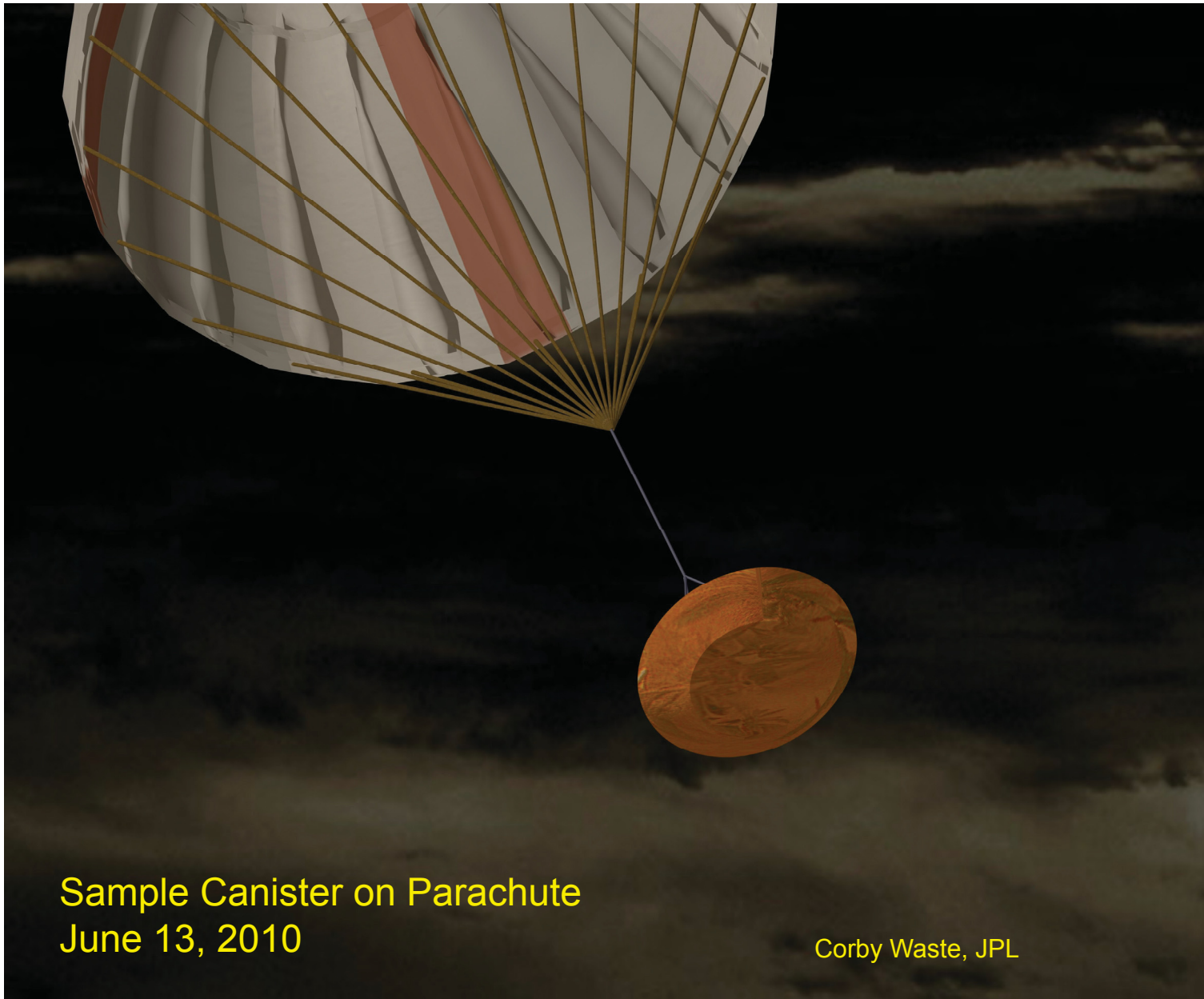
Reentry Fireball from NASA DC-8



Reentry Fireball from the Ground



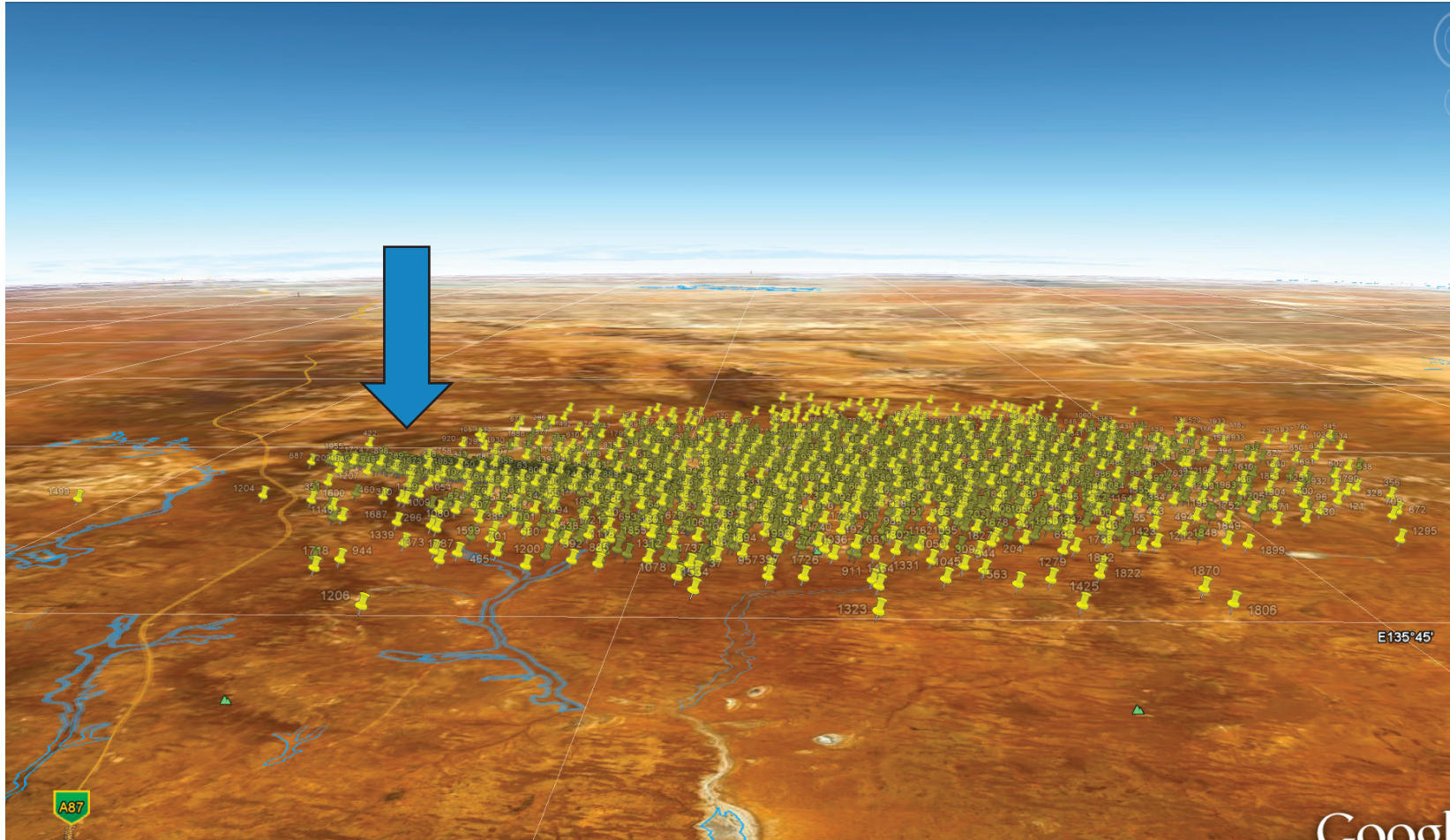
Hayabusa Reentry Fireball – 13 June 2010



Sample Canister on Parachute
June 13, 2010

Corby Waste, JPL

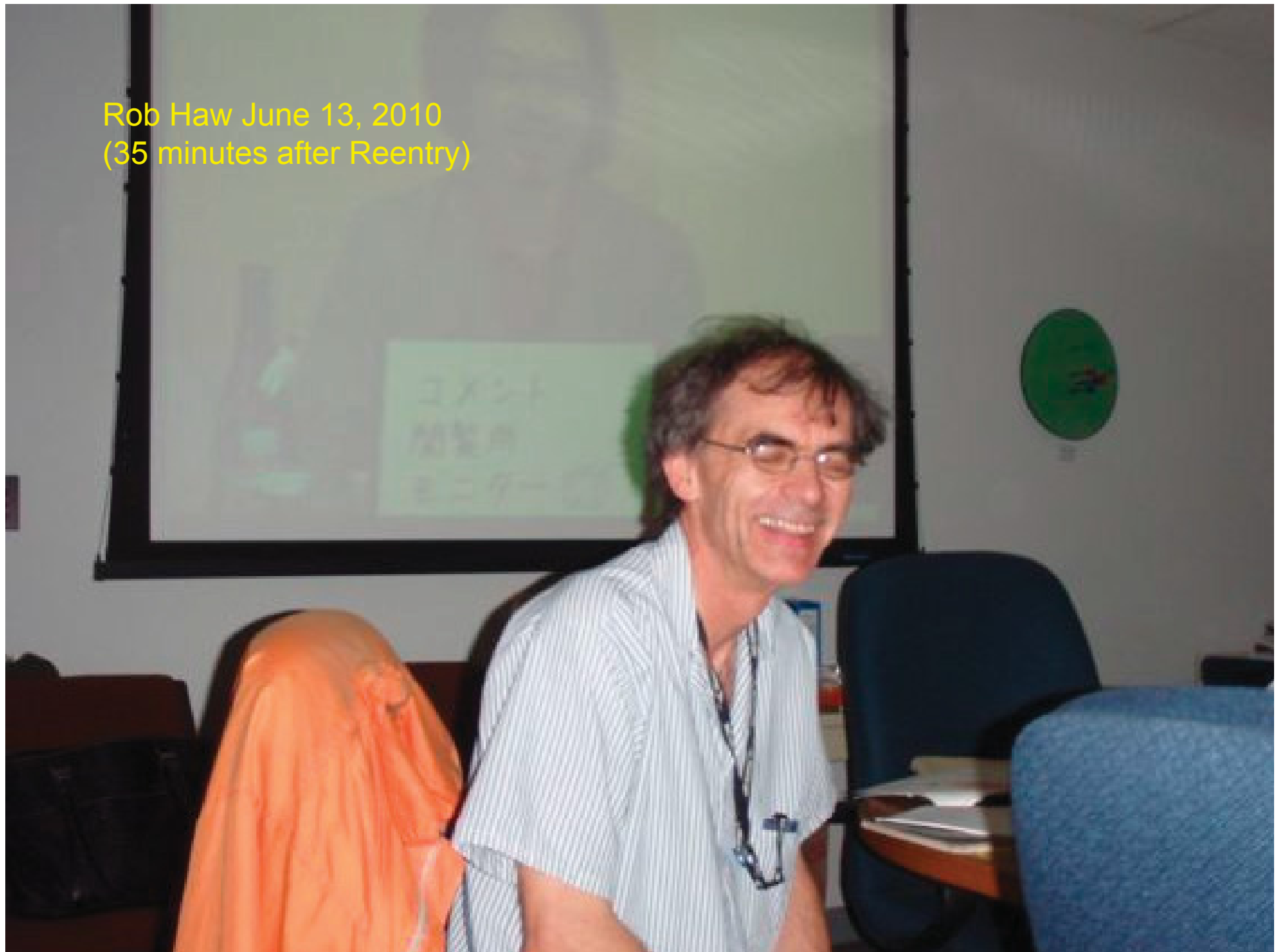
Hayabusa Landing Ellipse



JPL Navigation Team
June 13, 2010
(22 minutes after Reentry)



Rob Haw June 13, 2010
(35 minutes after Reentry)



Two Indigenous People who were taken to the recovery site first in order to determine whether any cultural precautions had to be taken at the site



Photo by Mike Zolensky, NASA JSC

Aerial view of the landing site of the Hayabusa Instrument Package



Photo by Mike Zolensky, NASA JSC

Capsule on the Ground



Hayabusa Instrument Package as found—it apparently landed and turned over as the parachute caught against a bush



Photo by Mike Zolensky, NASA JSC

Empty landing site, Hajime Yano (left), Masanao Abe (Deputy Hayabusa Curator, Mike Z



Photo by Mike Zolensky, NASA JSC

Delivery of the Hayabusa Instrument Package leaving the field



Photo by Mike Zolensky, NASA JSC

Delivery of the Hayabusa Instrument Package at the Woomera Ops Center



Photo by Scott Sandford, NASA ARC

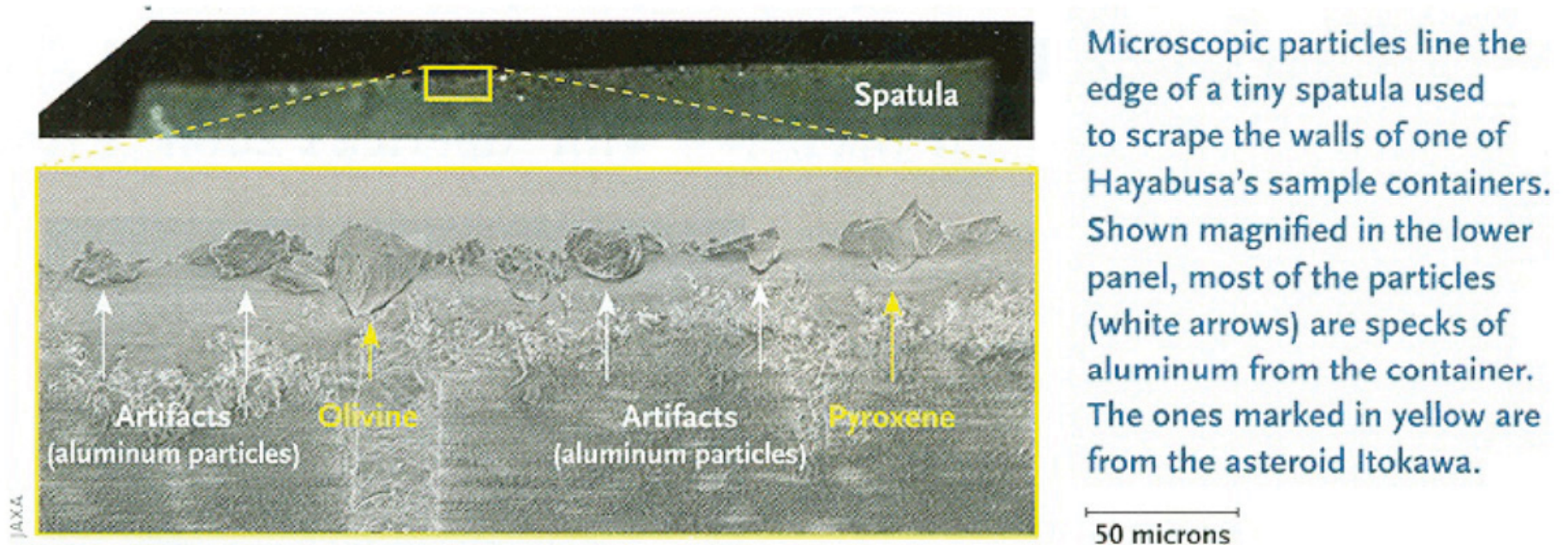
Hayabusa Instrument Package as received from the field, before being re-packaged in nitrogen-filled bags for shipment to Japan



Photo by Hajime Yano, ISAS/JAXA

Sky and Telescope Article*

February 2011



The results we were looking for, thanks to **electron microscopy**

**Based on JAXA press release, November 2010*

Key Players: DSN Reentry

- Belinda Arroyo and Cozette Parker (JPL, DSN Schedulers)
- Behzad Raofi, Steve Waldherr, Susan Kurtik (DSN Operations)
- Scott Riley, Romulo Paredes, Jesse Velasco, Greg Hewitt [Network Operations Project Engineers (NOPEs)]
- Leah Bangle, Vince Cuasay, Johnny Roy, Von Petrovich (Tracking Support Specialist [TSS])
- Danny Jimenez, Stan Agoot, Nancy Moran, Merle Mohring, Russell Anthony (Comm.)
- Jeff Hull, Marvin Simmons, David Scharpenberg, Jesse Umsted, Dee Terry (Ops Chiefs)

Key Players: Reentry Navigation

- Rob Haw
- Shyam Bhaskaran
- Mike Wilson*
- Jim Border
- Shadan Ardalan
- Chris Ballard
- Eric Graat
- Premkumar Menon
- Evgeniy Sklyanskiy
- Jonathon Smith
- Bill Strauss
- Powtawche Williams
- Hsi-Cheng Wu (software support)

*Personnel located in Japan

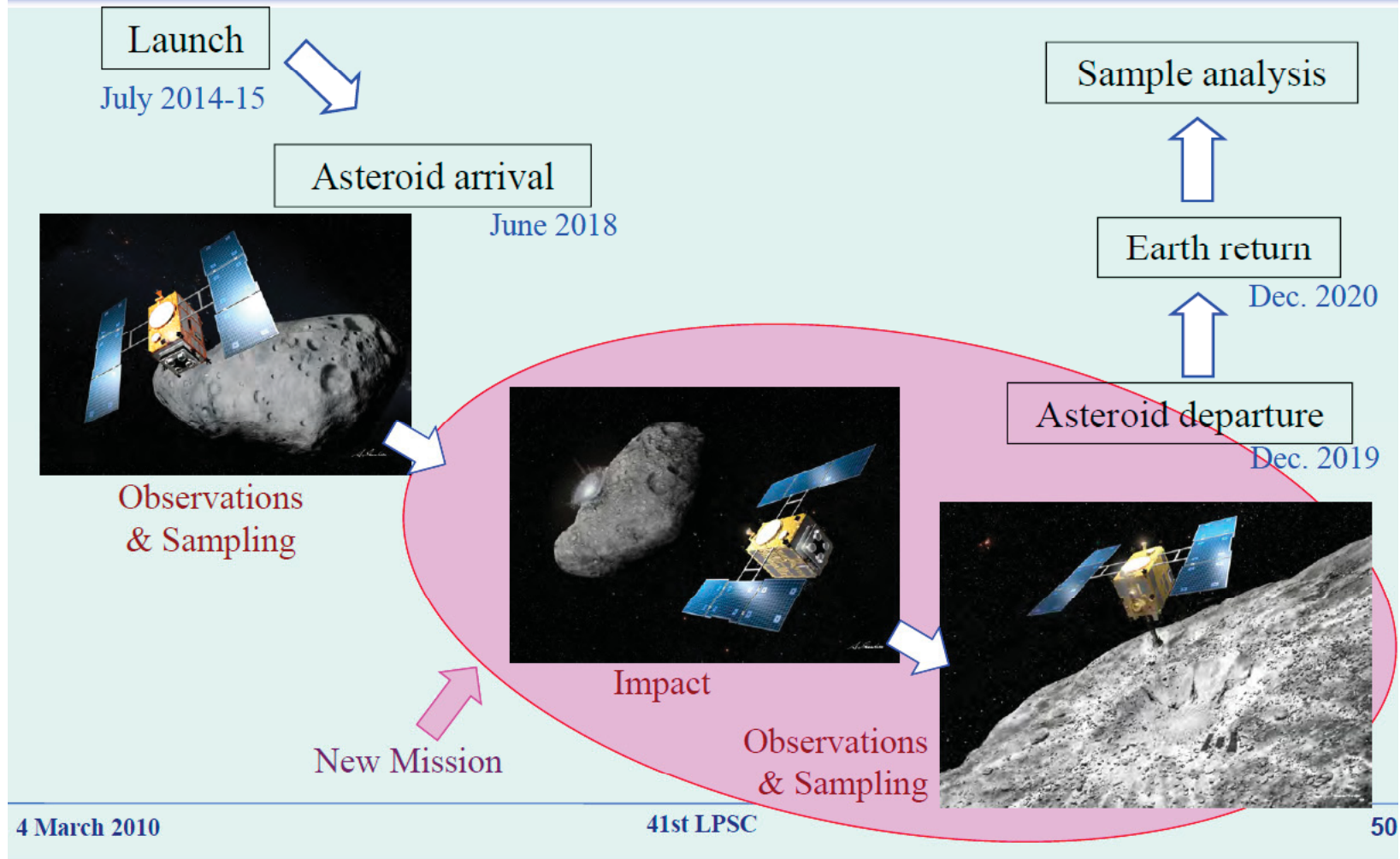
Hayabusa-2

Hayabusa-2

- Approved by JAXA in late 2010 for a new start in April 2011
 - C-Type Asteroid – 1999 JU3 – About kilometer in size
 - Carbonaceous chondrite, with organics and/or water
 - In Asteroid Belt, further away from the Sun than Itokawa
 - Launch in 2014 – Multiple launch opportunities to reach 1999 JU3 if launch slips
 - Basically a reflight of much of Hayabusa-1 spacecraft
 - Same sampling mechanism with some update
 - Will have a MINERVA and/or German-provided Rover
 - Landing at Woomera Range, Australia, again
 - NASA collaboration is TBD/being negotiated
-
- Launch – mid-2014
 - Earth Swing-by – late-2015
 - Arrival at Asteroid – mid-2018
 - Depart from Asteroid – late-2019
 - Sample Return to Earth – late-2020



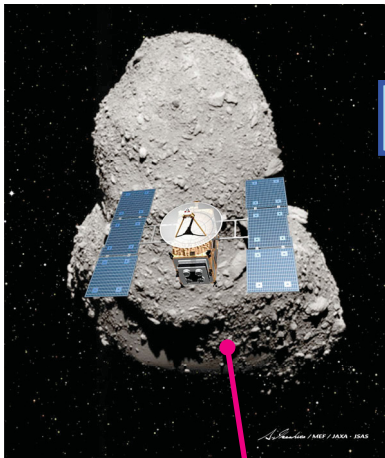
Mission Scenario of Hayabusa-2



Courtesy of Dr. Makoto Yoshikawa, JSPEC

Japan's Primitive Body Exploration Program

Hayabusa-1
2003–2010

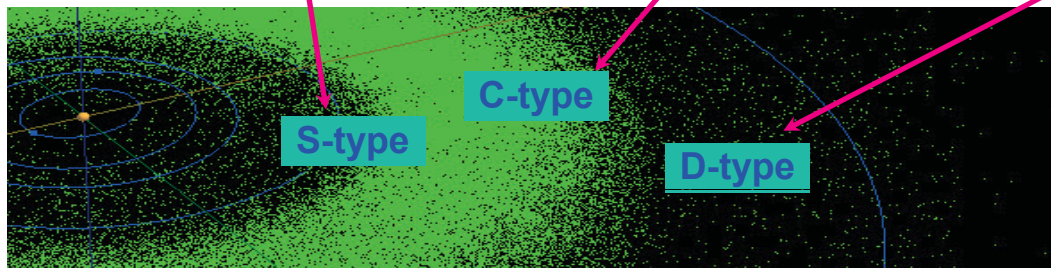
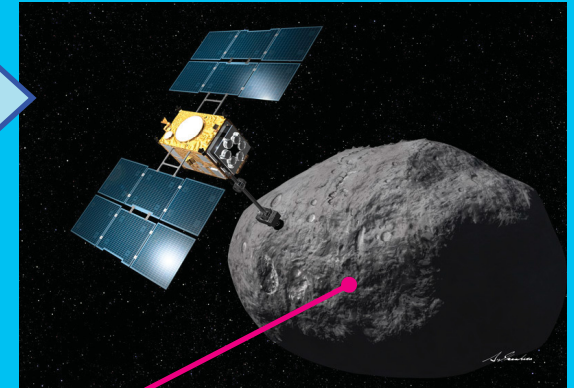


Post Hayabusa-1

Hayabusa-2



Hayabusa-Mk2



Asteroid Belt

Courtesy of Paul Abel, NASA JSC

さよなら Sayonara



ありがとう Arigato